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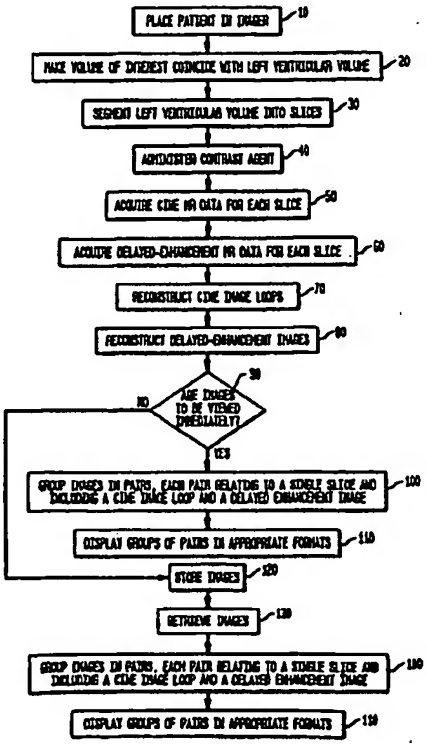
(54) Title: MULTI–PANELED DISPLAY FORMAT FOR MAGNETIC RESONANCE IMAGES OF A PATIENT'S LEFT VENTRICLE

(57) Abstract

MR images are acquired of slices of the left ventricle. For each slice, a pair of images is created. One of the images in the pair is a cine MR image loop and the other image is a delayed–enhancement MR image. The pairs are displayed on a display so that the cine MR image loop in each pair is visually associated with the delayed–enhancement image in that pair. This facilitates diagnosis because each image pair contains two different types of physiological information.



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# Multi-Paneled Display Format For Magnetic Resonance Images Of A Patient's Left Ventricle

## Cross-Reference to Related Application

This application is a continuation-in-part of application number 09/162,548, filed September 29, 1998 by the herein-named inventors and amended on November 30, 1998. The disclosure of this parent application is hereby incorporated herein as if fully set forth.

## Background of the Invention

The invention relates to cardiology, and more particularly relates to the display of images of the myocardium acquired using magnetic resonance imaging (MRI). In the most immediate sense, the invention relates to display of MRI images of the patient's left ventricle.

The above-referenced parent application discloses and claims a method of differentiating normal, injured, and infarcted myocardial tissue. In accordance with the therein-disclosed preferred embodiment of the invention, two categories of MR image data are acquired. The first category, namely motion-indicating image data (specifically, cine MR images), are used to determine whether the myocardium moves properly during the cardiac cycle. The second category - referred to herein as

delayed-enhancement MR images - is produced by administering contrast agent to the patient, waiting for a period of time, and then carrying out a contrast-enhanced MR study.

As is explained in the above-referenced parent application, normal myocardial tissue can be distinguished from abnormal myocardial tissue by the abnormal way the tissue moves during the cardiac cycle. Hence, normal myocardial tissue can be distinguished from abnormal myocardial tissue by acquiring a cine MR image (or other motion-indicating MR image) and noting regions where movement is abnormal. And, in accordance with the above-referenced parent application, it is now known that infarcted myocardial tissue produces a hyper-enhanced region on a delayed-enhancement MR image, while ischemic myocardial tissue does not.

Hence, by combining the information provided by these two types of MR images, it is possible to determine whether specific regions of the myocardium are normal (no hyper-enhancement in delayed-enhancement image, no abnormal motion-indicating image), injured but living (no hyper-enhancement in delayed-enhancement image, abnormal motion-indicating image), or infarcted (hyper-enhancement in delayed-enhancement image).

Although simultaneous display and use of both categories of image data can provide a significant diagnostic benefit, it can also create significant problems for the diagnostician. This is because conventional MR imagers and PACS workstations offer such a wide variety of display options that it is difficult to select exactly those options as will arrange the image data in such a way as to provide meaningful information that can be easily and quickly understood.

It is therefore one object of the invention to provide method and apparatus whereby both categories of image data can be presented in an easily understood format, permitting a cardiologist or other diagnostician to quickly assess the functionality of a patient's left ventricle.

Another object is to provide programmed display apparatus that can be used with existing MR imagers to display both categories of image data in this easily understood format.

Another object is, in general, to improve on method and apparatus of this general type.

The invention proceeds from the realization that pairs of MR images - each pair including a motion-indicating image and a delayed-enhancement image - provide a large quantity of diagnostically useful

information if the images in the pair relate to the same slice of the left ventricle. By looking at a particular pair of images, the diagnostician can quickly characterize regions of myocardium within those images as being normal, injured but living, and infarcted. And, by ordering the pairs according to the position within the heart that they represent, the diagnostician can immediately determine where those regions are located.

Advantageously, two or eight pairs of images are displayed simultaneously, so that 4 or 16 images are displayed at the same time. A 2 x 2 or 4 x 4 display format is commonly used, and is therefore preferred because cardiologists are comfortable with it. If the number of slices is such that all the images cannot be displayed at the same time, the images can be grouped; one group will be displayed first, another group displayed next, and the display process repeated as necessary until all the images have been displayed.

## Brief Description of the Drawings

The invention will be better understood with the aid of the illustrative and non-limiting drawings, in which:

Fig. 1 shows short-axis slices of a human left ventricle;

Fig. 2 shows a typical pair of MR images of the type relating to each of the slices shown in Fig. 1;

Fig. 3 shows long-axis slices of a human left ventricle;

Fig. 4 shows a typical pair of MR images of the type relating to each of the slices shown in Fig. 3;

Fig. 5 shows a 4 x 4 display format in accordance with a preferred embodiment of the invention;

Fig. 6 shows a 2 x 2 display format in accordance with the preferred embodiment of the invention;

Fig. 7 is a flowchart of a preferred embodiment of the invention; and

Fig. 8 is a schematic illustration of apparatus used in accordance with the invention.

## Detailed Description of Preferred Embodiments

It is presently believed that a cardiologist or other diagnostician carrying out a study of the function of a patient's left ventricle will wish to review approximately six to eight "short axis" slices of the ventricle (eight short axis slices SA1, SA2, SA3, SA4, SA5, SA6, SA7 and SA8 are shown in Fig. 1) and approximately two "long axis" slices of the ventricle (two long axis slices LA1 and LA2 are shown in Fig. 3). Although six to eight short-axis and two long-axis slices are presently preferred, the number of slices is not part of the invention.

In accordance with the disclosure contained in application number 09/162,548 filed September 29, 1998, two images are acquired at each of the slice locations using MRI. One image is a motion-indicating image. As is disclosed therein, the motion-indicating image is a cine image, taken over at least one cardiac cycle. Such a cine image shows movement of the left ventricle. Advantageously, the cine image is a loop that repeats itself. This repetition allows the cardiologist to focus upon particular regions of the myocardium, permitting the cardiologist to distinguish regions that move normally from regions that do not.

The other image is a delayed-enhancement image, on which infarcted (dead) regions of the myocardium show up as hyper-enhanced. By looking at both images simultaneously, a diagnostician can distinguish between normal, injured but living, and infarcted regions of the patient's myocardium.

In accordance with the invention, these acquired images are paired on a slice-by-slice basis (see Figs. 2 and 4) and one or more groups of the pairs are displayed simultaneously. (In Figs. 2 and 4, the cine images are shown with arrows that indicate movement of the left ventricle during the cardiac cycle.) Advantageously, they are displayed in a 4 x 4 format (Fig. 5) wherein

sixteen panels show eight pairs of images. The first pair relates to the ventricular slice SA1 at the base of the left ventricle, the second pair relates to the neighboring slice SA2, and the third through sixth pairs relate to slices SA3 ... SA6 that progressively approach the tip of the left ventricle. The seventh and eighth pairs relate, respectively, to long axis slices LA1 and LA2.

This format is particularly advantageous because it permits the diagnostician not only to quickly identify the existence of ischemic and infarcted myocardial tissue, but also to quickly localize such tissue in the myocardium.

This 4 x 4 format need not be maintained for all groups of pairs. For example, after a group of eight pairs of short-axis images (not shown) has been reviewed using the 4 x 4 format, a group of two long-axis images can be displayed in a 2 x 2 format (Fig. 6). This makes it easy and convenient for the cardiologist to confirm or correct his or her impression of the location of any abnormal tissue, because the long-axis and short-axis images are at right angles to each other.

In the preferred embodiment as illustrated in Figs. 5 and 6, the motion-indicating image is a cine image. Although this is presently preferred, it is not required.

Other motion-indicating MR images can be used instead. For example, it would be possible to use a "tagged" image in which distortion of a pattern of reference lines is used to indicate movement of the myocardium, or even a static image in which degrees of motion are indicated visually (as by correlating grayscale or color-coded information with degree of motion).

In the preferred embodiment as illustrated in Figs. 5 and 6, the delayed-enhancement image is located below the corresponding cine image loop. This is not required; the delayed-enhancement image could alternatively be located above the cine image loop or to either side of it. While the specific relationship between these two images is not a part of the invention, there must be a consistent visual association between them.

Likewise, although a square format (2 x 2, 4 x 4) is preferred because it fits existing displays and is familiar to radiologists, this format is not necessary. If the display had the appropriate size and shape, it would be possible to e.g. display eight pairs of images in a single line going up and down or right and left.

Hence, in accordance with the preferred embodiment of the invention (see Figs. 7 and 8), a patient 200 is placed in an MR imager 210 (step 10) and the volume of interest is made to coincide with the left ventricular

volume (step 20). The left ventricular volume is then segmented into a plurality of slices (step 30); advantageously, six to eight short-axis slices and two long-axis slices. Then, contrast agent such as Gd-DTPA is administered to the patient (step 40).

After administration of the contrast agent, cine MR data is acquired (step 50) for each of the slices. (Injection of contrast agent is unrelated to acquisition of cine MR image data.) This data collection may require from ten to ninety minutes; a typical cine MR data acquisition might be thirty minutes. After these data have been collected, delayed-enhancement MR data (step 60) are collected for each of the slices.

Although in the preferred embodiment the delayed-enhancement data are collected after collection of the cine data (i.e. step 60 follows step 50), this is not necessary. It merely makes productive use of the delay between the administration of the contrast agent and the acquisition of delayed-enhancement data, and thereby shortens the time required to collect all necessary data. Furthermore, although in accordance with the preferred embodiment the motion-indicating MR data are of the cine type, this is not required, and other motion-indicating data (e.g. tagged cine data) can be acquired instead.

This alternative may make it desirable to change the order in which the data are collected.

Then, the cine MR data are used to reconstruct cine MR image loops (step 70), and the delayed-enhancement MR data are used to reconstruct delayed-enhancement MR images (step 80).

If the reconstructed images are to be viewed immediately (step 90 is "yes"), they are then displayed on the main console 220 of the MR imager. The reconstructed images are grouped into pairs, each pair relating to a single slice and including a cine MR image loop and a delayed-enhancement MR image (step 100). Then, the pairs are displayed in groups (step 110) on the main console display 220. When the group of eight short-axis image pairs are displayed, they are displayed in a 4 x 4 format wherein the pairs are in the same sequence as are the slices. When the group of two long-axis image pairs are displayed, they are displayed in a 2 x 2 format, wherein the pairs are also in the same sequence as the slices.

If the reconstructed images are not to be viewed immediately (step 90 is "no"), or if the main console 220 of the MR imager is not adapted to display them in accordance with the invention, they may be stored (step 120), retrieved (step 130), grouped (step 100) and

displayed (step 110) later on in an appropriately programmed display at a remote console 230.

Although one or more preferred embodiments have been described above, the scope of the invention is defined only by the following claims:

## Claims

1. A method of conducting a magnetic resonance (MR) study of the left ventricle of a patient's heart, said left ventricle having a long axis and a short axis, the method comprising the following steps:

segmenting the left ventricular volume into a plurality $N \geq 2$ of slices;

acquiring, for each of the N slices, a motion-indicating MR image showing ventricular motion in that slice over at least one cardiac cycle;

acquiring, for each of the N slices, a delayed-enhancement MR image of that slice;

dividing the plurality of N motion-indicating MR images and delayed-enhancement MR images into $G \geq 1$ groups; and

simultaneously displaying one group of images including I motion-indicating MR images and I delayed-enhancement MR images, said one group being displayed in such a manner as to create I image pairs wherein the motion-indicating MR image showing ventricular motion in a particular slice is visually associated with the delayed-enhancement MR image of that slice.

2. The method of claim 1, wherein each of the slices is parallel to an axis of the left ventricle.

3. The method of claim 2, wherein at least one of the slices is parallel to the long axis of the left ventricle and at least one of the slices is parallel to the short axis of the left ventricle.

4. The method of claim 1, wherein the simultaneously displaying step is carried out in a manner that the I slices together define a contiguous subvolume within said left ventricular volume.

5. The method of claim 1, wherein I is chosen such that 2I is an integral power of 2.

6. The method of claim 1, wherein each motion-indicating MR image is a cine MR image.

7. The method of claim 6 wherein each cine MR image is a cine loop and wherein the I simultaneously displayed cine MR image loops are in phase and are temporally synchronized.

8. A method of conducting a magnetic resonance (MR) study of the left ventricle of a patient's heart, comprising the following steps:

segmenting the left ventricular volume into a plurality N ≥ 2 of slices;

acquiring, for each of the N slices, a cine MR image showing ventricular motion in that slice over at least one cardiac cycle;

formatting each acquired cine MR image into a cine MR image loop in a manner that all the cine MR image loops have identical phases and durations;

acquiring, for each of the N slices, a delayed-enhancement MR image of that slice;

dividing the plurality of N cine MR image loops and N delayed-enhancement MR images into G ≥ 1 groups each having S slices in each group, S being capable of varying from one group to another but being chosen such that 2S is always an integral power of 2; and

simultaneously displaying one group of S cine MR image loops and S delayed-enhancement MR images in such a manner as to create S image pairs wherein

the cine MR image loop showing ventricular motion in a particular slice is visually associated with the delayed-enhancement MR image of that slice,

the image pairs are ordered to correspond to slices that together define a contiguous subvolume within the left ventricular volume, and

adjacent image pairs relate to adjacent slices of the left ventricular volume.

9. Apparatus for displaying magnetic resonance (MR) images of slices through the left ventricle of a patient's heart, comprising:

means for receiving a plurality N of motion-indicating MR images, each motion-indicating MR image showing ventricular motion within a corresponding one of said slices;

means for receiving a like plurality N of delayed-enhancement MR images, each delayed-enhancement MR image showing the ventricle within a corresponding one of said slices;

means for pairing the motion-indicating MR images with the delayed-enhancement MR images to form a like plurality N of image pairs, each pair containing a motion-indicating MR image showing ventricular motion in a particular slice and a delayed-enhancement MR image of the ventricle in that slice; and

means for displaying the N image pairs in a format wherein the motion-indicating MR image in a pair is visually associated with the delayed-enhancement MR image in that pair.

10. The apparatus of claim 9, wherein the slices are arranged in an order and wherein the image pairs are arranged in a like order.

11. The apparatus of claim 9, wherein the motion-indicating MR images are cine images.

12. The apparatus of claim 11, wherein the cine images are image loops.

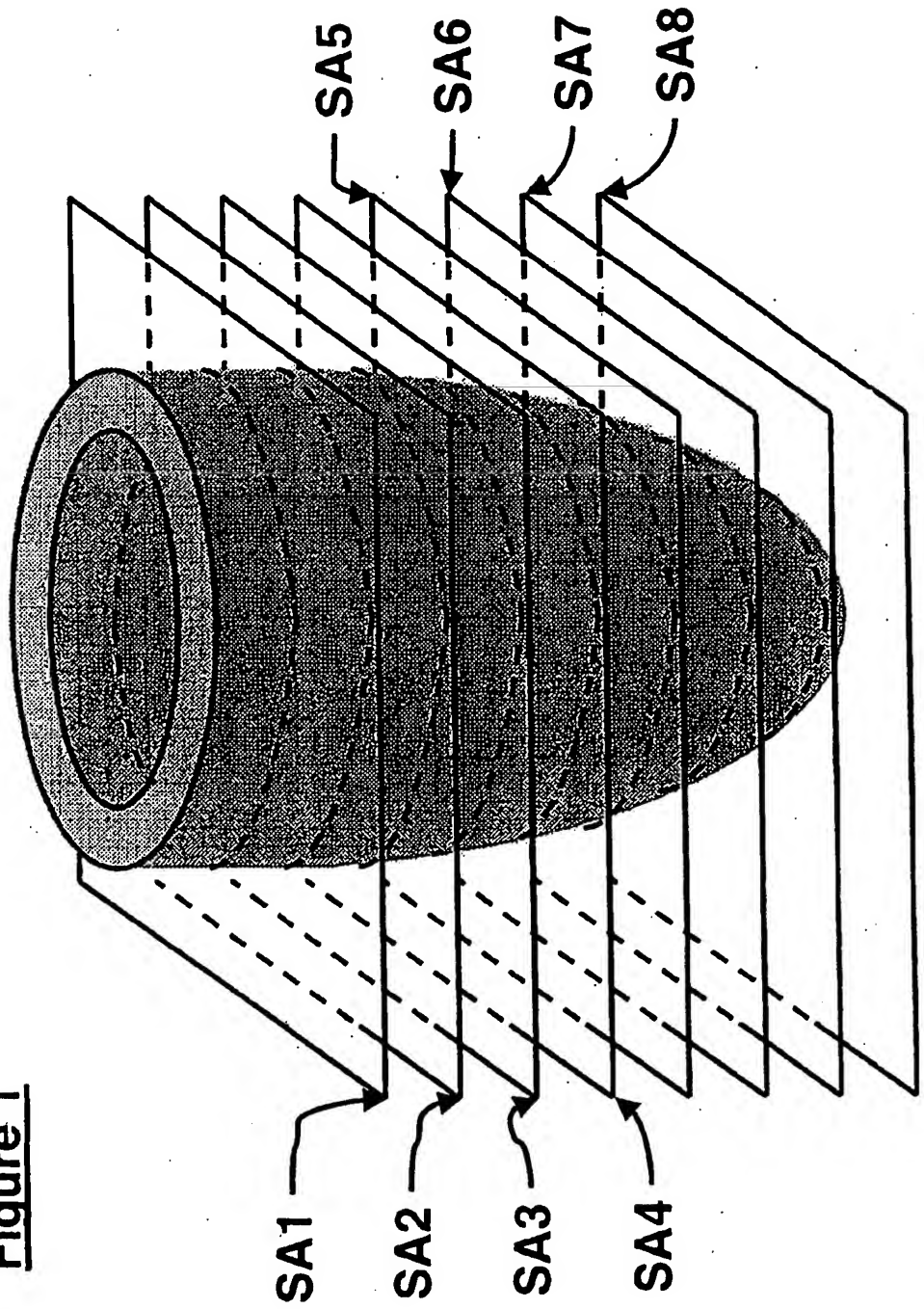



Figure 1

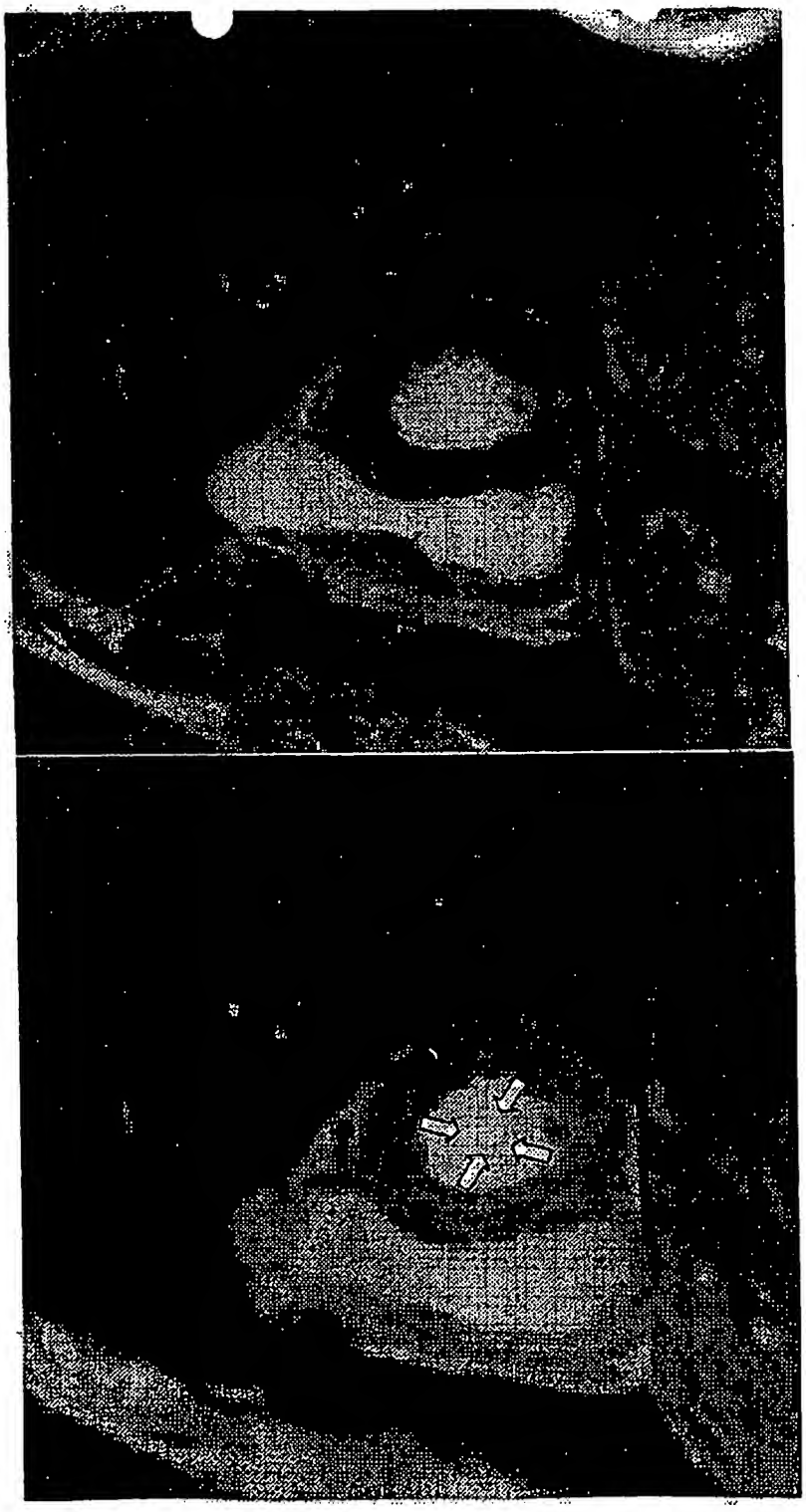



Figure 2

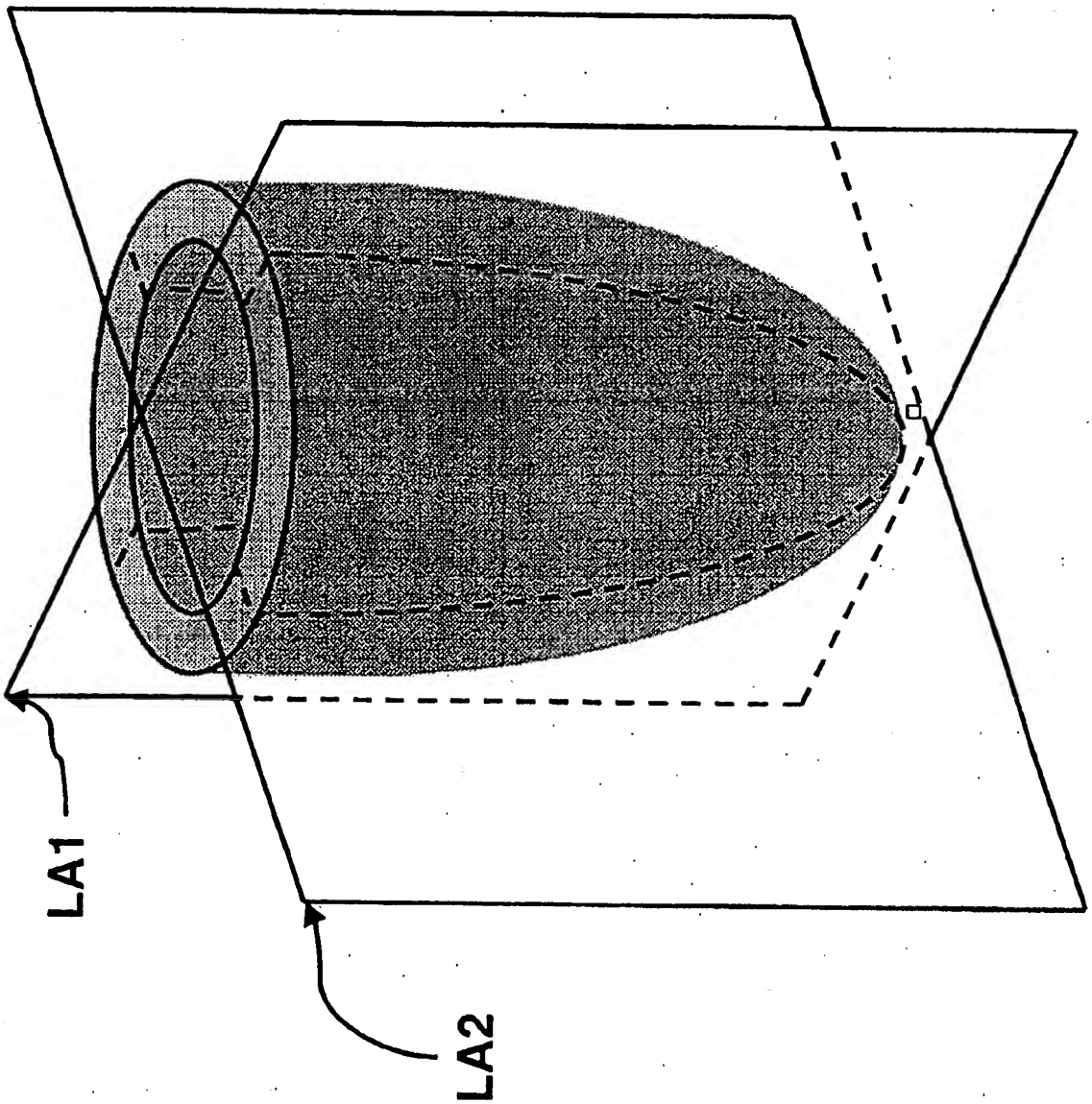



Figure 3

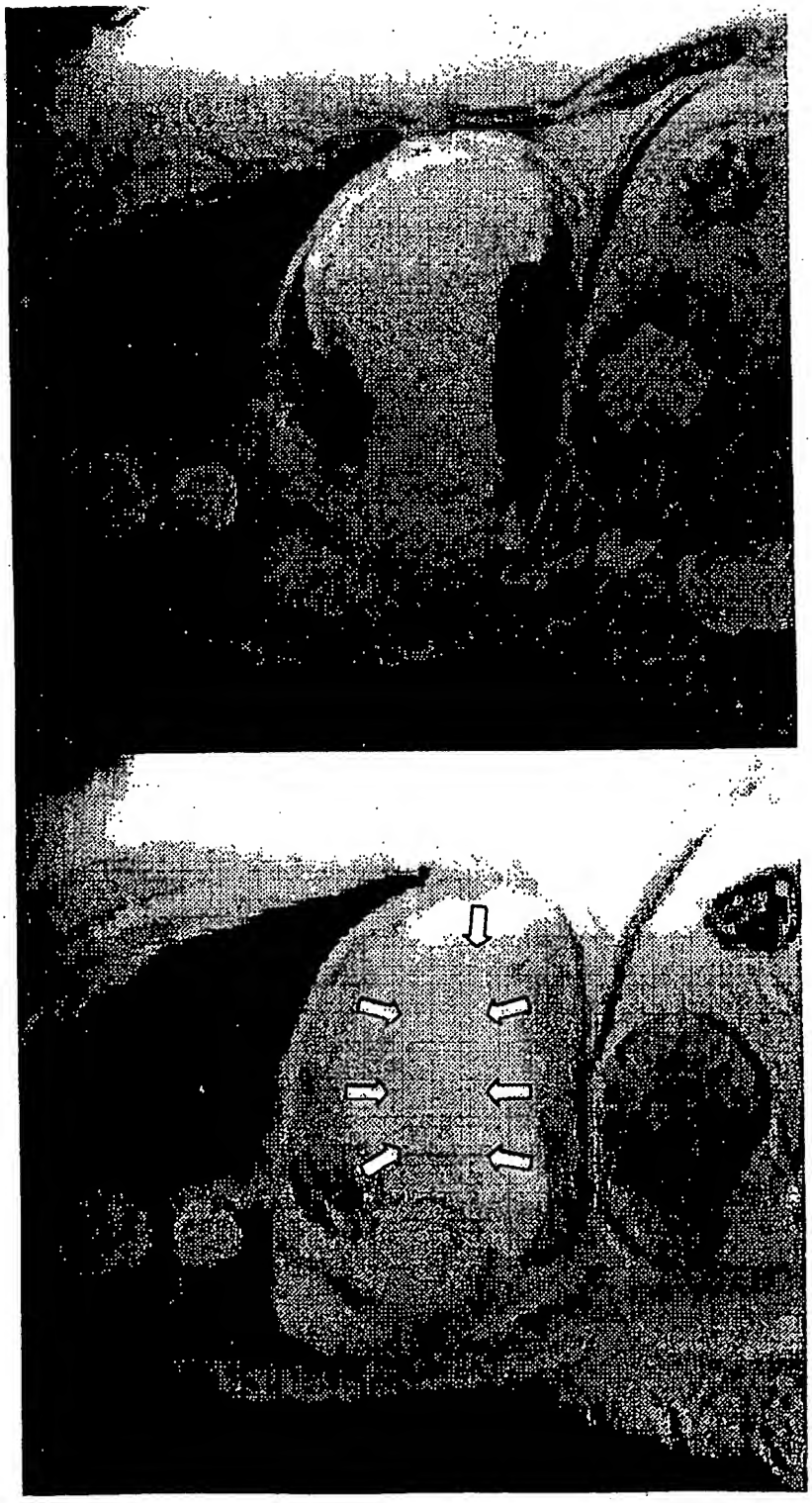



Figure 4

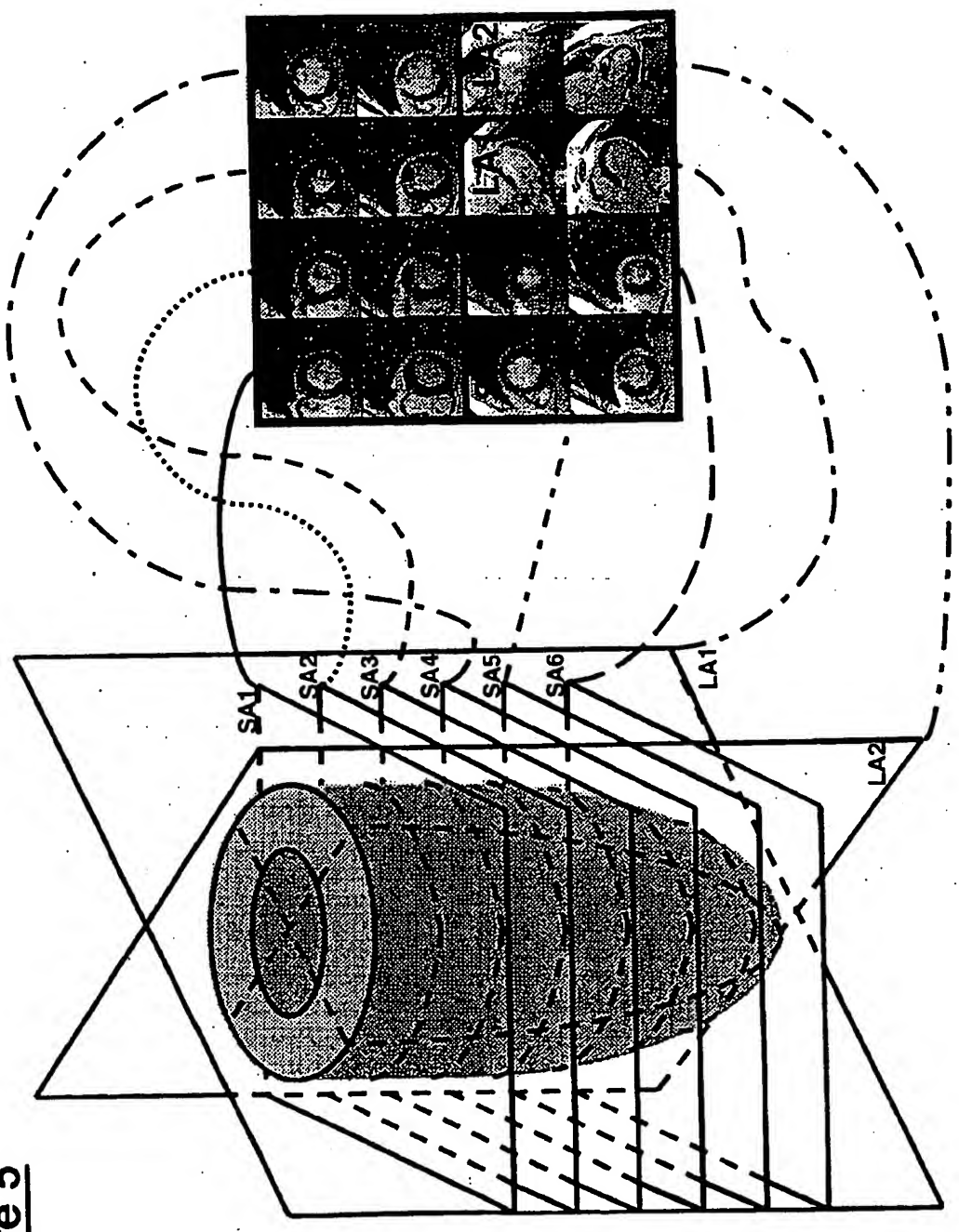



Figure 5

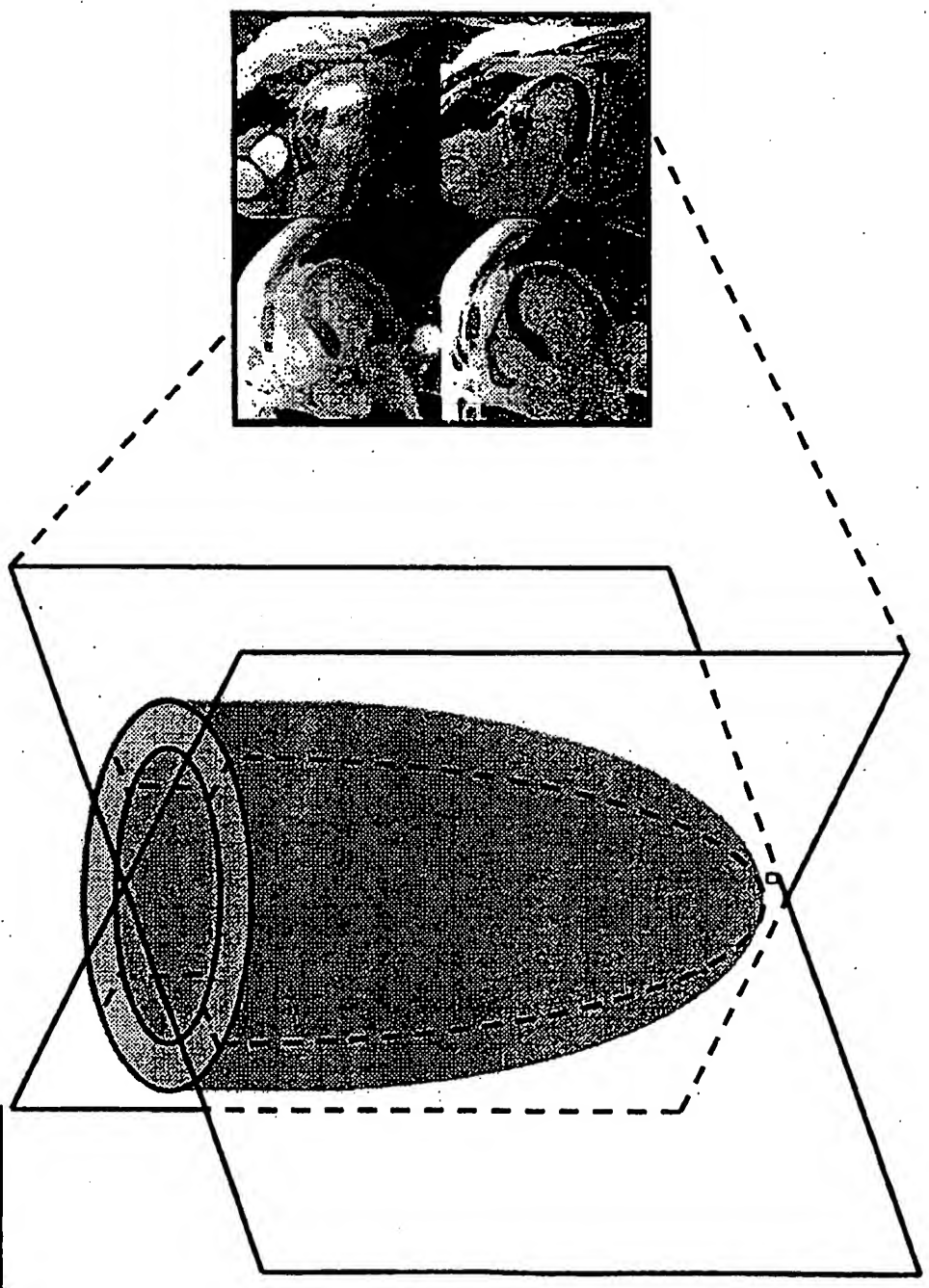
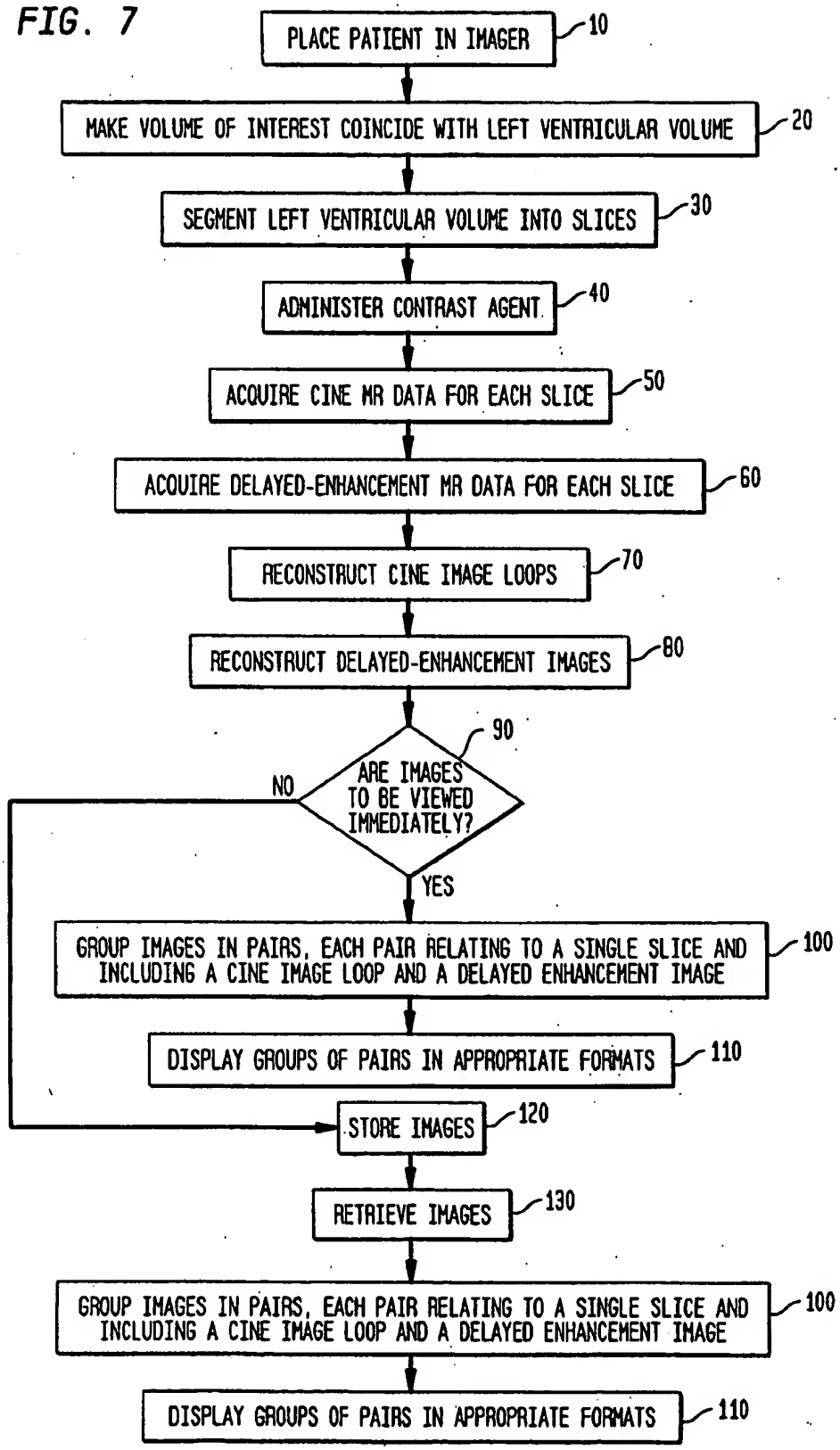


Figure 6

FIG. 7


PLACE PATIENT IN IMAGER
10
MAKE VOLUME OF INTEREST COINCIDE WITH LEFT VENTRICULAR VOLUME
20
SEGMENT LEFT VENTRICULAR VOLUME INTO SLICES
30
ADMINISTER CONTRAST AGENT
40
ACQUIRE CINE MR DATA FOR EACH SLICE
50
ACQUIRE DELAYED-ENHANCEMENT MR DATA FOR EACH SLICE
60
RECONSTRUCT CINE IMAGE LOOPS
70
RECONSTRUCT DELAYED-ENHANCEMENT IMAGES
80
ARE IMAGES TO BE VIEWED IMMEDIATELY?
90
NO
YES
GROUP IMAGES IN PAIRS, EACH PAIR RELATING TO A SINGLE SLICE AND INCLUDING A CINE IMAGE LOOP AND A DELAYED ENHANCEMENT IMAGE
100
DISPLAY GROUPS OF PAIRS IN APPROPRIATE FORMATS
110
STORE IMAGES
120
RETRIEVE IMAGES
130
GROUP IMAGES IN PAIRS, EACH PAIR RELATING TO A SINGLE SLICE AND INCLUDING A CINE IMAGE LOOP AND A DELAYED ENHANCEMENT IMAGE
100
DISPLAY GROUPS OF PAIRS IN APPROPRIATE FORMATS
110

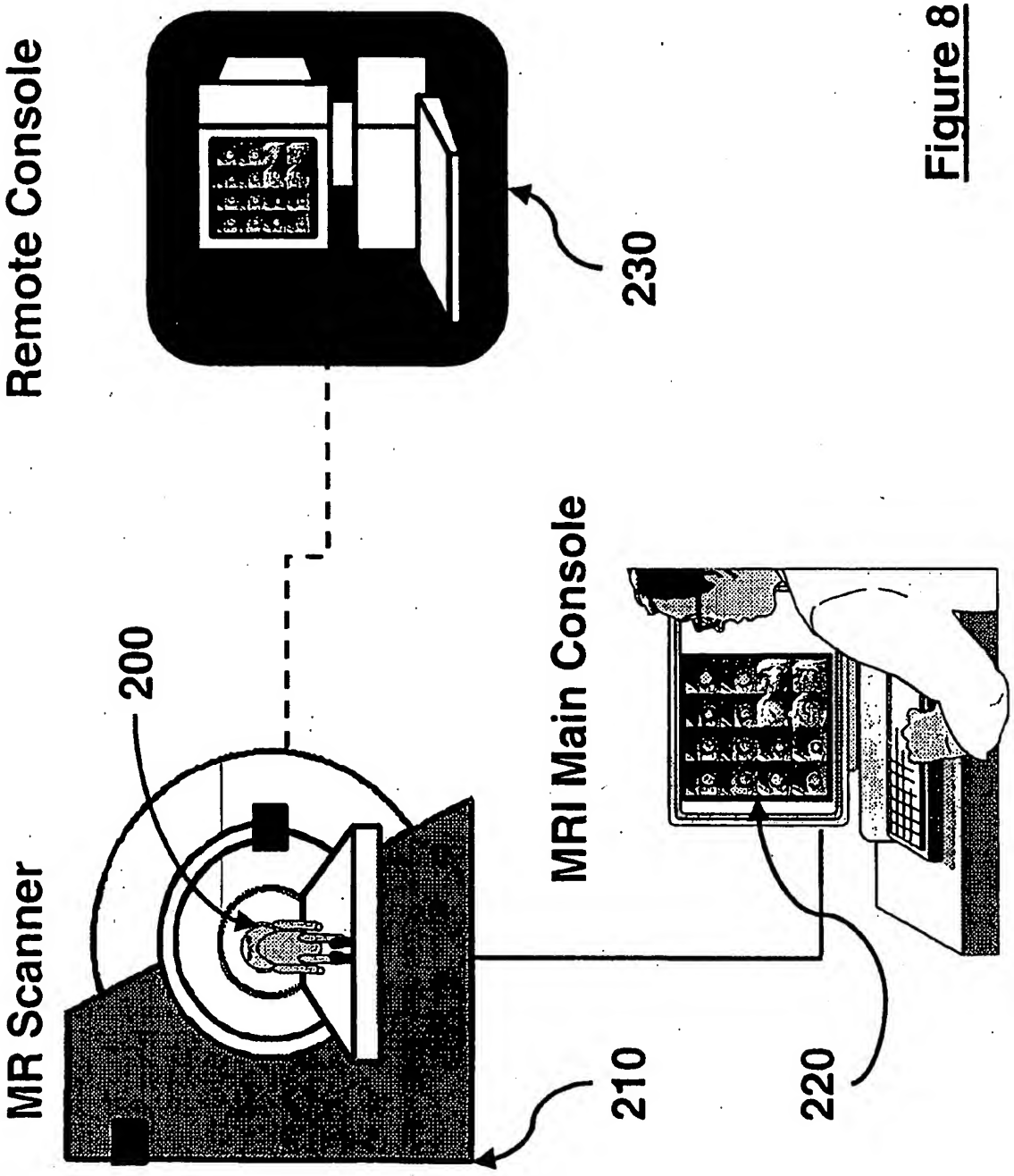



Figure 8

# INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/US 00/00360

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01R33/56 G01R33/28

According to International Patent Classification (IPC) or to both national classification and IPC

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IPC 7 G01R

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| X | D.L.KRAITCHMAN ET AL.: "Accurate characterization of myocardial viability with Gadophrin-2" PROCEEDINGS OF THE INTERNATIONAL SOCIETY FOR MAGNETIC RESONANCE IN MEDICINE, SIXTH SCIENTIFIC MEETING AND EXHIBITION, SYDNEY, AUSTRALIA, APRIL 18-24, 1998, vol. 1, page 552 XP002136406 see the whole abstract<br>-/- | 1-12 |

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Inter nal Application No
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| Category * | Citation of document, with indication,where appropriate, of the relevant passages | Relevant to claim No. |
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| X | HOLMAN E R ET AL: "QUANTITATIVE ANALYSIS OF REGIONAL LEFT VENTRICULAR FUNCTION AFTER MYOCARDIAL INFARCTION IN THE PIG ASSESSED WITH CINE MAGNETIC RESONANCE IMAGING" MAGNETIC RESONANCE IN MEDICINE,US,ACADEMIC PRESS, DULUTH, MN, vol. 34, no. 2, 1 August 1995 (1995-08-01), pages 161-169, XP000520104 ISSN: 0740-3194 see the whole document | 1-12 |
| X | H.KAWAMITSU ET AL.: "Analysis of Myocardial Motion with Velocity Encoding Cine MRI - Noninvasive Objective Detection of Myocardial Infarction" PROCEEDINGS OF THE INTERNATIONAL SOCIETY FOR MAGNETIC RESONANCE IN MEDICINE, FIFTH SCIENTIFIC MEETING AND EXHIBITION, VANCOUVER, B.C., CANADA, APRIL 12-18, 1997, vol. 2, page 903 XP002136409 see the whole abstract | 1-12 |
| A | T.B.PARRISH ET AL.: "High resolution 3D contrast enhanced MRI of chronic myocardial infarction" PROCEEDINGS OF THE INTERNATIONAL SOCIETY FOR MAGNETIC RESONANCE IN MEDICINE, SIXTH SCIENTIFIC MEETING AND EXHIBITION, SYDNEY, AUSTRALIA, APRIL 18-24, 1998, vol. 2, page 894 XP002136410 | 1,8,9 |

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Inter al Application No
PCT/US 00/00360

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication,where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | B.R.COWAN ET AL.: "Regional Analysis of Left Ventricular Motion After Myocardial Infarction" PROCEEDINGS OF THE INTERNATIONAL SOCIETY FOR MAGNETIC RESONANCE IN MEDICINE, SIXTH SCIENTIFIC MEETING AND EXHIBITION, SYDNEY, AUSTRALIA, APRIL 18-24, 1998, vol. 2, page 884 XP002136411 | 1-5,8-10 |

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